CREATING AN "ELECTROMAGNETIC INTERFERENCE RISK DISTRIBUTION MAP" IN THE MODERN HOSPITAL

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Abstract- **Electromagnetic Interference (EMI) from various sources can cause medical monitoring equipment and other hospital devices to malfunction, that can range from mere inconvenience to serious problems. Comprehensive induced Magnetic Field and Real Electromotive Force measurements have been carried out and properly documented in the form of an "on line risk distribution map" covering all departments in the General District Anti-Cancer Hospital of Piraeus "Metaxa".**
Keywords **- Electromagnetic Interference, Hospital Safety.**

I. INTRODUCTION

Electromagnetic interference (EMI) constitutes a growing problem that occurs when electromagnetic waves emitted by one device interfere with the normal operation of another. Sensitive electronic components inside any equipment that relies on computer chips can be vulnerable to other electromagnetic energy. Electromagnetic compatibility (EMC) refers to the capability of electronic devices to function properly in an electromagnetic environment. EMI events are rare, since they occur only under certain condition and depend on the distance and the power of the interfering source. EMC problems have been recognized and dealt with for years in the industry, however, health-care personnel are not trained to be aware of the associated problems and to identify possible events.

The result of medical-device malfunction ranges from potential patient death to mere inconvenience, and such problems are usually emerging in medical equipment that were built 10 to 15 years ago, when EMI was not recognized as a serious issue. However, the employment in the near future of complex wireless communication and patient data transmission networks, will also lead to more EMI problems, because many contemporary medical devices are not supposed to function in this kind of electromagnetic environment.

There are some crucial decisions that should be made in each hospital, concerning the dealing with the influence of EMI on the spatial and functional planning of the departments and units. These decisions are of non-medical nature, but they have a direct bearing on the operation of the whole structure. Therefore, we have carried out comprehensive induced Magnetic Field and Real Electromotive Force measurements, and we have properly documented them, in the form of an "on line risk distribution map", covering all available departments, in the General District Anti-Cancer Hospital of Piraeus "Metaxa".

Thus, we attempted to develop a system to address problems and decisions, which lend themselves to being supported by such an information correlation, and facilitate hospital engineers, physicians and nurses to become gradually familiar, with the handling of issues and events, associated to EMC.

II. METHODOLOGY

Equipment can produce interference as electromagnetic fields or as disturbance signals on lines and cables. Both types of interference have to fulfil requirements, quoted from typical emission standards. All electronic equipment including electromedical equipment in the EU has to fulfil the European Communities Directive on Electro Magnetic Compatibility (EMC). Industrial testing is mostly carried out using the international standard IEC 601-1-2 [1], which has been adopted as the harmonized European Standard, number EN 60601-1-2 [2], and their recent revisions.

The IEC 601-1-2 applies to medical electrical equipment and systems including the Information Technology Equipment (ITE), for example computer equipment, or a processor board, which is part of the medical equipment. The standard also differentiates between Emission and Immunity. Emission relates to the interference in the environment caused by the equipment; Immunity means no susceptibility of equipment to disturbances from the environment. In the IEC 601-1-2 reference is made to the emission and immunity tests from several standards describing test set-ups and measurement methods. For emission tests equipment is categorized as Group 1or Group 2 with regard to emitted energy. In Group 1 equipment, high frequency energy is produced specifically for the internal functioning of the equipment, for example a PC with an internal clock of 100 MHz. In Group 2 equipment, the high frequency energy is applied to the patient. Equipment is further categorized with regard to the location of their use. Equipment for home use is Class B and other equipment is Class A. Finally, the Medical Devices Directive (93/42/EEC) also addresses electromagnetic interference issues.

TABLE I
EQUIPMENT ACCORDING TO EMITTED ENERGY AND HOSPITAL AREAS CHECKED

Group 1 equipment /European Standards [3]	**Department**	**Map**
Medical imaging	Ambulance	√
Diagnostic X-ray systems (EN 60601-2-7)	Emergency	√
Computed tomography (EN 60601-2-44)	In vitro Labs	√
Nuclear Medicine Systems (EN 60601-2-17)	Blood Bank	√
Monitoring	Radiology	√
Electroencephalography (EN 60601-2-26)	Nuclear Med.	√
Therapy	ICU / CCU	√
Therapeutic X-ray systems (EN 60601-2-8)	Surgery	√
Ultrasound therapy equipment (EN 60601-2-5)	Radiotherapy	√
Infusion pumps (EN 60601-2-24)	Wards	√
Radiant warmers (EN 60601-2-21)	Aux. Facilities	√
Group 2 equipment /European Standards [3]		
Medical imaging		
Magnetic resonance imaging (EN 60601-2-33)		
Therapy		
SW diathermy equipment (EN 60601-2-3)		
HF Surgical equipment (EN 6060-2-2)		

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Abstract

Subject Terms

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For the purposes of this project, the Magnetic Field Intensity around the potential emission sources has been measured, by employing a Metron Norway QA5 measuring device. Additional measurements of the true root mean square (RMS) value of the induced electromotive force (EMF) by the presence of a time varying magnetic field, on a coil of one turn enclosing an area of about 0.1 m^2 have also been carried out, by employing an appropriate home-developed device. These two parameters, can be easily measured in every hospital, have a very good reproducibility, and there is a variety of commercially available equipment at low cost.

In the United States [4],[5], FDA has considered adopting IEC 60601-1-2 as a guideline for evaluating the safety and efficacy of products but has identified some deficiencies, most notably, that it does not clearly define failure criteria. As written, the standard allows a manufacturer to define a "pass" result of a required EMC test as "failing safe." FDA would prefer to indicate that the equipment must meet the criterion of maintaining clinical utility. In order to meet this FDA indication, we have further setup in the Hospital and in the Biomedical Technology Laboratory of the Department several "high probability electromagnetic interference circumstances". Fixed and mobile EMI sources were combined to equipment supporting and/or monitoring vital functions and it was observed if the criterion of maintaining clinical utility were met.

Magnetic Field measurements have been carried out in the Outpatient Department, in the ICU, the Operating Theater and other critical areas of the Hospital, as indicated in Table II. The most relevant of the acquired data were inserted on layouts of the corresponding departments, creating, thus, a sort of magnetic field intensity "navigation map" through the Hospital Departments.

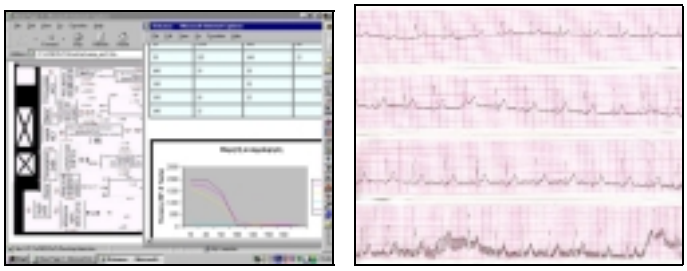

Fig. 1. View of linked pages of the EMI presentation system (left). Power supply self-interference caused on an old-fashioned EKG device (right).

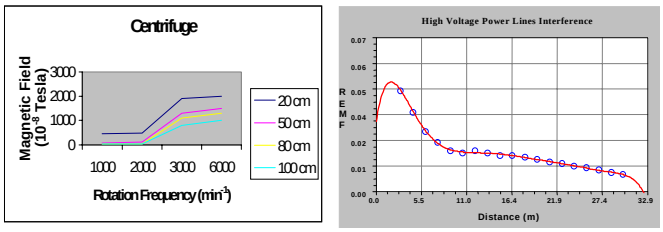

Fig. 2. Typical Magnetic Field profiles around a Centrifuge depending on the rotation frequency and for several distances (left). Typical Real Electromotive Force vs. Distance profiles near High Voltage Power lines (right).

III. Results

The results are presented according to Hospital Department and are included into a developed information system, based on HTML, in order to be easily reached by all Hospital Departments, on a controlled-access Web-site. The acquired data are inserted on digitized layouts of the corresponding departments. Highlighted hotspots link points or regions of interest on the layout to other pages, including spreadsheets containing detailed experimental raw-data and profiles of the measured fields.

The induced magnetic field around the suspicious devices was measured for several distances and directions. Here, only the maximal intensity (B_{max}) values, in a distance of 10 cm are presented. OR means over-range, that is an intensity value higher than $2x10^{-5}$ Tesla.

A. *Ambulance and Emergency Department*

The most important source of interference is the Electrosurgery Unit of the Emergency Operating room. In effect all such equipment are creating high EMI and their positioning relative to monitors and other sensible devices should be carefully checked.

TABLE II
AMBULANCE AND EMERGENCY DEPARTMENTS: TYPICAL DEVICES CHECKED

Ambulance and Emergency Department			
Device Type	**B_{max} 10^{-8} Tesla**	**Device Type**	**B_{max} 10^{-8} Tesla**
Surgery Lamp	1000	Fundus Camera	1600
Electrosurgery 1	OR	Ophth. Projector	1300
Electrosurgery2	OR	Acouometer	800

B. *In vitro Laboratories and Blood Bank*

As expected, all devices employing electrical motors are creating considerable EMI. It should be kept in mind that both, the orientation and the rotation frequency influence the final interference, and the most sensible receptors seems to be the microprocessors of the analyzers located nearby.

TABLE III
IN VITRO LABORATORIES AND BLOOD BANK: TYPICAL DEVICES CHECKED

In vitro Laboratories and Blood Bank			
Device Type	**B_{max} 10^{-8} Tesla**	**Device Type**	**B_{max} 10^{-8} Tesla**
Microscope Fluo	630	Abbot IMX	630
Mixer	OR	Abbot Washer	1640
Photometer1	1000	Abbot Quantum	OR
Photometer2	470	Haem-centrifuge	500
Refrigerator	30	Microcentrifuge	OR
Adhering Device	1800	HPLC	100
Blood Refriger.	290	Centrifuge Floor	1500
Plasma Defrost	200	Ventilated Hood	OR
Haem. Analyzer	1100	Electrophoresis	1600
Aggregometer	470	Densitometer	OR
Centrifuge Table	OR	Incubator	630

C. *Radiology and Nuclear Medicine*

TABLE IV
MEDICAL IMAGING: TYPICAL DEVICES CHECKED

Radiology and Nuclear Medicine			
Device Type	**B_{max} 10^{-8} Tesla**	**Device Type**	**B_{max} 10^{-8} Tesla**
Ultrasound SL2	1200	Printer GT 2/2	1600
Ultrasound SL	1000	PC Hyundai	OR
CT Philips	930	PC Philips	OR
Mobile Practix	1280	Waterbath	50
Mobile Siregraf	1320	Mixer Vortex	OR
Mammography	OR	Mixer CIS	1150
" Console	245	Centrifuge Table	500
Bucky Siemens	OR	Serum Dispenser	210
X-rays Illumin.	950	Dosimeter PTW	OR
Film Processor1	1010	Survey Xetex	OR
Film Processor2	500	GammaCamera1	300
Beta Counter	830	GammaCamera2	OR
Gamma Counter	1980	Film Processor3	900

The Mobile X-rays units constitute a potential EMI hazard source for the ICU and the Wards. In Nuclear Medicine Area, the employment of Dose Rate Meters and Survey Meters, during patent examinations, may also influence the readings. Finally, by the relative positioning of new equipment, the corresponding EMI profiles should be taken into account.

D. *Intensive Care Unit and Surgery*

In any EMI problem [6], there must be a source of an electromagnetic phenomenon, a receptor that cannot function properly due to the electromagnetic phenomenon, and a path between them that allows the source to interfere with the receptor. Identifying one of these generally helps to solve electromagnetic compatibility problems. The ICU/CCU and the Operating Rooms are the Hospital areas where plenty of devices could alternatively play the role of the source and/or of the receptor, as it is easily recognized in the following table.

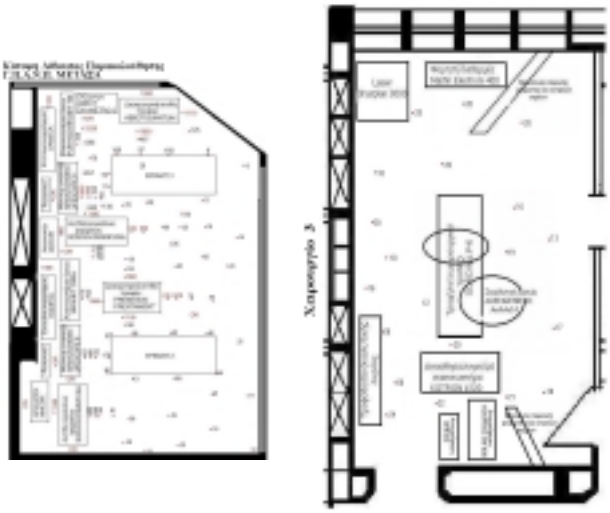

Fig. 4. Typical layouts of an ICU room (left), and of an Operation theater (right) marked with the measured Magnetic Field Intensity in 10^{-8} Tesla.

TABLE V
INTENSIVE CARE UNIT AND SURGERY: TYPICAL DEVICES CHECKED

Intensive Care Unit and Surgery			
Device Type	**B_{max} 10^{-8} Tesla**	**Device Type**	**B_{max} 10^{-8} Tesla**
Operating Lamp	125	Dosim. Pump1	1540
Suction Pump1	240	Dosim. Pump2	1540
Monitor1	1900	Power Supply	OR
Anesthesia	1600	Suction Pump3	1700
Electrosurgery1	1800	Electrosurgery2	OR
Blood Heater	1980	Suction Pump4	OR
Mobile Lamp	1000	Oximeter2	OR
Power supply	1500	Capnograph	1000
Oximeter1	160	Ventilator Vol.	1900
Suction Pump2	700	Cranial Pressure	OR
Blood Gas Anal.	1600	Cardiac Output	OR
Electrolytes ISE	400	Central Unit ICU	OR
Centrifuge	1500	Monitor2	OR
Osmometer	OR	Dosim. Pump3	OR
Ventilator	1100	Monitor3	431

Furthermore, the mutual proximity of the equipment and their employment coincidence, create several paths of interference.

E. *Radiotherapy*

The measurements are presented on the following layout:

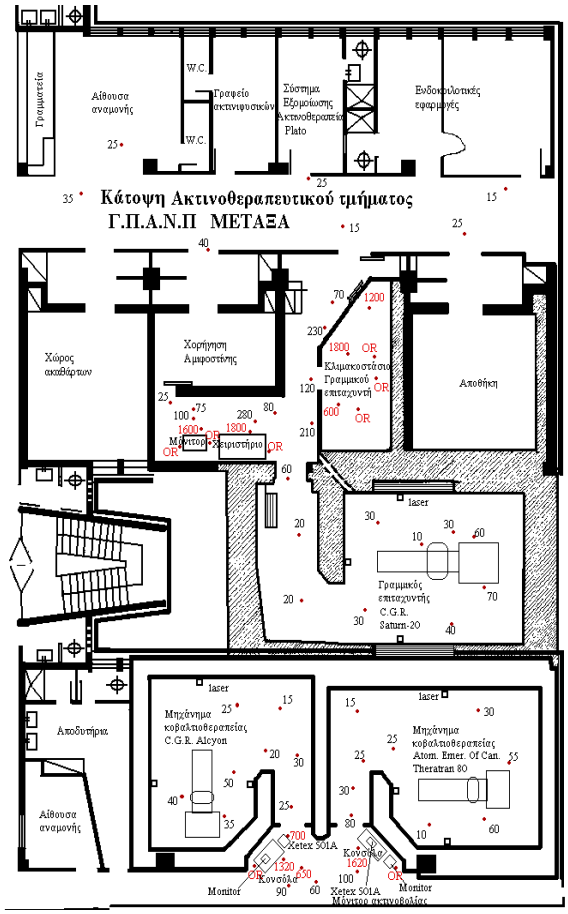

Fig. 5. Layout of the Radiotherapy facility marked with the measured Magnetic Field Intensity in 10^{-8} Tesla.

F. *Wards and Auxiliary Facilities*

TABLE VI
WARDS AND AUXILIARY FACILITIES: MOBILE PHONES CHECKED

Wards and Auxiliary Facilities: Mobile Phones			
Device Type	**B_{max} 10^{-8} Tesla**	**Device Type**	**B_{max} 10^{-8} Tesla**
Telital 400	110	Ericson GF788	1800
Siemens	500	Ericson GA628	305
Nokia 5110	1100	Ericson 388	1480
Panasonic G600	980	Philips Twist	1240
Panasonic G520	500	Bosch Multiband	1580

Since in the Wards and the auxiliary facilities of the Hospital, there is no additional interfering equipment, beyond the described, it is interesting to append here the results of some random and non-representative measurements, on visitors' mobile telephones, which have been used in these areas. In a like manner to the other measurements, only the maximal intensity (B_{max}) values, in a distance of 10 cm are presented.

G. *Laboratory forced probable EMI conditions*

Several combinations of equipment often located nearby in real hospital conditions, and which eventually might cause EMI, were set-up side to side, in source-receptor pairs, in our Laboratory, and the performance of the receptor was observed. Some of the results are presented in the following TableVII:

TABLE VII
LABORATORY SIMULATED EMI "HIGH RISK CONDITIONS"

Source of EMI	**Receptor**	**Observation**
Electrosurgery	ICU Monitor	Disturbance
Defibrillator	ICU Monitor	Disturbance
Electrosurgery	CO2/O2 Meter	Negative
Wireless Network	ICU Monitor	Negative
Centrifuge Table	Coagulometer	Negative
Centrifuge Table	Coulter Counter	Negative
X-ray Mobile	ICU Monitor	False Alarm
27 MHz Therapy	Portable PC	Disturbance

IV. DISCUSSION

Magnetic Field measurements have been carried out in the Outpatient Department, in the ICU, the Operating Theater and other critical areas of the Hospital, by employing an one-turn coil, as Electromagnetic Compatibility and Interference detector. An information system was developed, to accommodate the results, based on HTML, in order to be easily reached by all Hospital Departments, on a controlled-access Web-site. The most important of the acquired data were inserted on digitized layouts of the corresponding departments. Highlighted hotspots link points or regions of interest on the layout to other pages, including spread-sheets containing detailed experimental raw-data, graphics of the measured fields, profiles of reactive near-field, radiating near field, and far field regions etc.

Further, means are provided for the introduction of periodically accomplished quality assurance data and the creation of temporal correlation, inasmuch as necessary. Finally, previous positive experience has encouraged us to incorporate digital, audio and video assisted, educational and self-evaluation means, pertaining to the features of the department, equipment or activities under investigation.

V. CONCLUSION

No significant interference was detected, under real world conditions, in the whole hospital, with the exception of a "self-interfering" power supply of an old fashioned EKG device. The system has been successfully tested under “real world” conditions in the Regional General anti-Cancer Hospital of Piraeus “Metaxa”, assisting the interested parties to identify any of the three elements that contribute to the creation of Electromagnetic Interference events and to eliminate at least one of them. Finally, it becomes obvious that the used on-line media, offer a cost-effective "digital alternative" to achieve the synthesis of technical-managerial subject-matter to theoretical and methodological issues in the Hospital

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